# AVAILABILITY-BASED IMPORTANCE FRAMEWORK FOR SUPPLIER SELECTION

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# THE BASIC IDEA

- We want a means to incorporate an ability to meet **system availability needs** into the supplier selection process
  - Addressing "**how do we build in system availability in the supplier selection process?**"

- We do this by determining
  - How **important** a component is to system availability
  - How well a **supplier** performs in providing that important component

# FUNDING SOURCE, PUBLISHED RESULTS

- Naval Postgraduate School Assistance Grant/Agreement No. N00244-14-1-0027 awarded by the NAVSUP Fleet Logistics Center San Diego
  - The views expressed here do not necessarily reflect the official policies of the Naval Postgraduate School

- Two published/accepted journal articles
  - Gravette, M.A. and K. Barker. 2014. Achieved Availability Importance Measures for Enhancing Reliability Centered Maintenance Decisions. *Journal of Risk and Reliability*, **229**(1): 62-72.
  - Hague, R.K., K. Barker, and J.E. Ramirez-Marquez. 2015. Interval-valued Availability Framework for Supplier Selection Based on Component Importance. Accepted in *International Journal of Production Research*.

# Methodological background

Integrated framework for supplier selection

Concluding remarks

# METHODOLOGICAL BACKGROUND

- We integrate several ideas to the selection of sole-source suppliers for component parts
  - Availability-based importance measures
  - Multi-criteria decision analysis
  - Interval arithmetic

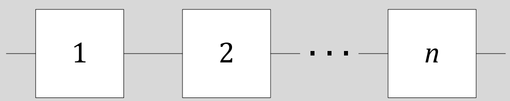
# AVAILABILITY IMPORTANCE MEASURES

- **Availability** broadly combines **reliability** (mean time between failure, MTBF) and **maintainability** (mean time to repair, MTTR)

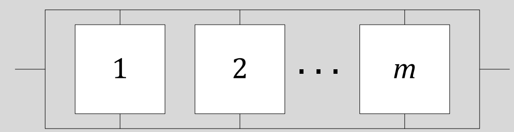
$$\text{Availability} = \frac{\text{uptime}}{\text{uptime} + \text{downtime}} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

# AVAILABILITY IMPORTANCE MEASURES

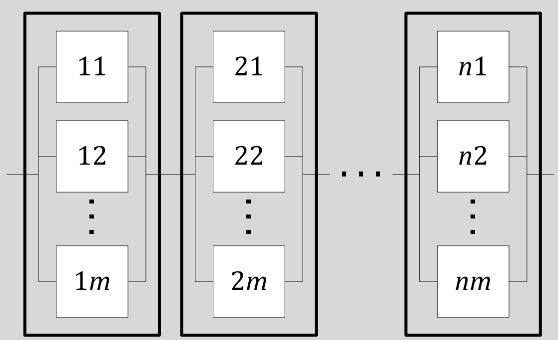
- For many traditional systems, **availability** can be calculated **analytically**




series




parallel

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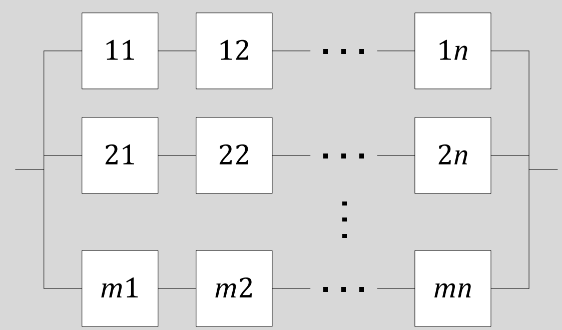



parallel-series

# AVAILABILITY IMPORTANCE MEASURES

- **Importance measures** have often been used in reliability engineering to determine how **important** a component is to the overall **performance of the system**
  - e.g., Birnbaum importance for system reliability, $\mathrm{I}_i^B = \frac{\partial R_s}{\partial R_i}$

- Gravette and Barker [2014] considered **availability** as a system performance measure $I_i^A = \frac{\partial A_s}{\partial A_i}$

# AVAILABILITY IMPORTANCE MEASURES

- For example, the availability of a **series-parallel** system

$$A^{\mathrm{SP}} = \prod_{i=1}^{n}\left[\coprod_{j=1}^{m} A_{\mathrm{a}_{ij}}\right] = \prod_{i=1}^{n}\left[1 - \prod_{j=1}^{m}\left(1 - \frac{\mathrm{MTBF}_{ij}}{\mathrm{MTBF}_{ij} + \mathrm{MTTR}_{ij}}\right)\right]$$

- Therefore, the importance of **parallel component** $j$ in **subsystem** $i$ would then be

$$\mathrm{I}_{ij}^{\mathrm{SP}} = \frac{\partial \mathrm{A}^{SP}}{\partial \mathrm{A}_{ij}}$$

$$= \prod_{k \neq i}^{n}\left[1 - \prod_{l=1}^{m}\left(1 - \frac{\mathrm{MTBF}_{kl}}{\mathrm{MTBF}_{kl} + \mathrm{MTTR}_{kl}}\right)\right] \times \prod_{l \neq j}^{m}\left(1 - \frac{\mathrm{MTBF}_{il}}{\mathrm{MTBF}_{il} + \mathrm{MTTR}_{il}}\right)$$

# MULTI-CRITERIA DECISION ANALYSIS

- We want to choose a sole supplier based on how **effectively** it can supply **available components** in the system

- Therefore, we have **multiple criteria**: the **availability** of each component in the system
- And we can **weight** those components according to how **important** they are

- So we need a **multi-criteria decision analysis** technique to rank suppliers

# MULTI-CRITERIA DECISION ANALYSIS

- We choose a technique called **TOPSIS**
  - Technique for Order Preferences by Similarity to an Ideal Solution
  - Common in supplier selection problems

- Based on the idea of a compromise solution
  - Closeness to the best solution, distance from the worst solution

# MULTI-CRITERIA DECISION ANALYSIS

- What we do with TOPSIS: compare several **alternatives** across **multiple weighted criteria**

**Availability provided by each supplier for each component**

Sole suppliers

| | Criterion 1 | Criterion 2 | $\cdots$ | Criterion $C$ |
|---|---|---|---|---|
| Alternative 1 | $x_{11}$ | $x_{12}$ | $\cdots$ | $x_{1C}$ |
| Alternative 2 | $x_{21}$ | $x_{22}$ | $\cdots$ | $x_{2C}$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\ddots$ | $\vdots$ |
| Alternative $B$ | $x_{B1}$ | $x_{B2}$ | $\cdots$ | $x_{BC}$ |
| Weights | $w_1$ | $w_2$ | $\cdots$ | $w_C$ |

**Weights determined by component importance**

# INTERVAL ARITHMETIC

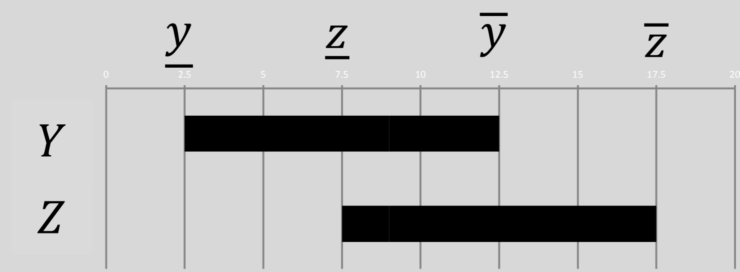
- There will likely be **uncertainty** associated with component availability provided by each supplier
  - Reliability is uncertain
  - Maintainability is uncertain

- And we may **not** have a **probability distribution** describing this uncertainty
  - "Forcing" a distribution when it is not known for sure could do more **harm** to the decision making process than good

# INTERVAL ARITHMETIC

- We represent uncertainty with an **interval**
  - Assume we know a **lower bound** and an **upper bound** of metrics of interest (e.g., MTBF, MTTR)

- We can use a decision rule to compare $Y$ and $Z$




$$Y \succ Z \iff \begin{cases} \underline{y} > \underline{z} & \text{Best case} \\ \overline{y} > \overline{z} & \text{Worst case} \\ \left(\underline{y} + \overline{y}\right) > \left(\underline{z} + \overline{z}\right) & \text{Laplace} \\ \theta\left(\underline{y} - \underline{z}\right) > (1-\theta)(\overline{y} - \overline{z}), \theta \in [0,1] & \text{Hurwicz} \\ \left(\overline{y} - \underline{z}\right) > \left(\overline{z} - \underline{y}\right) & \text{Min regret} \end{cases}$$

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# FRAMEWORK FOR SUPPLIER SELECTION

- We integrate the existing methodologies into a **four-step framework**

**Step 1. Calculate the interval-valued availability importance for each component**
Based on historical performance or OEMs, importance is determined reflecting uncertainty using intervals

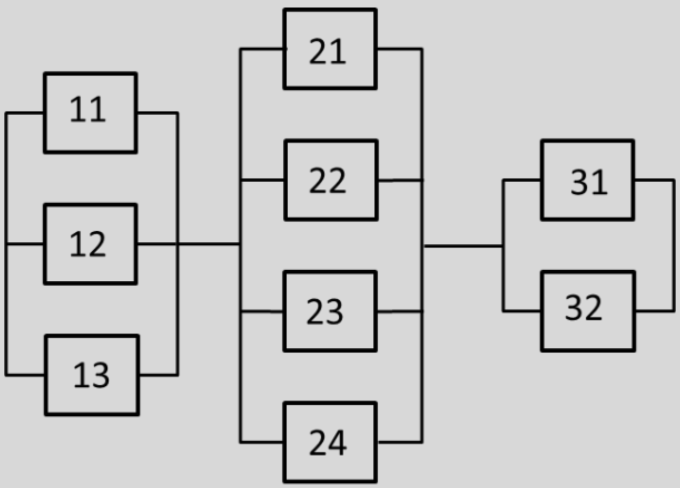
**Step 2. Rank component according to availability importance**
Interval arithmetic decision rules used to rank components according to their importance in contributing to availability of the system

**Step 3. Calculate weights for components**
Interval availability importance of each component is used to calculate a scalar importance weight, with all weights summing to 1

**Step 4. Apply TOPSIS to select supplier**
Suppliers compared with multi-criteria decision analysis technique, where interval availability for component $i$ acts as the $i$th decision criterion, weighted by the importance of that component in the availability of the system

# ILLUSTRATIVE EXAMPLE

- We applied the approach to a **series-parallel system**, inspired by an aircraft servo-actuation system




| Component | $\underline{MTBF}$ | $\overline{MTBF}$ | $\underline{\mathrm{MTTR}}$ | $\overline{MTTR}$ |
|---|---|---|---|---|
| $C_{11}$ | 25 | 35 | 1 | 5 |
| $C_{12}$ | 365 | 395 | 2 | 7 |
| $C_{13}$ | 150 | 165 | 1 | 8 |
| $C_{21}$ | 150 | 200 | 2 | 5 |
| $C_{22}$ | 75 | 110 | 1 | 6 |
| $C_{23}$ | 185 | 200 | 3 | 5 |
| $C_{24}$ | 120 | 125 | 1 | 3 |
| $C_{31}$ | 365 | 465 | 1 | 1.5 |
| $C_{32}$ | 365 | 485 | 1 | 2 |

# ILLUSTRATIVE EXAMPLE

- Based on the intervals for MTBF and MTTR, we **rank the importance** of the nine components
  - Risk neutral **Laplace rule**

| Component | Laplace criterion $\left(\underline{\mathrm{I}_{ij}^{SP}} + \overline{\mathrm{I}_{ij}^{SP}}\right)$ | Rank |
|---|---|---|
| $C_{11}$ | 0.0123 | 5 |
| $C_{12}$ | 0.0501 | 3 |
| $C_{13}$ | 0.0347 | 4 |
| $C_{21}$ | 0.0022 | 8 |
| $C_{22}$ | 0.0016 | 9 |
| $C_{23}$ | 0.0059 | 6 |
| $C_{24}$ | 0.0093 | 7 |
| $C_{31}$ | 0.2532 | 1 |
| $C_{32}$ | 0.2203 | 2 |

# ILLUSTRATIVE EXAMPLE

- We have **interval-valued availability** capabilities for each component from each of **four suppliers**

| Component | Supplier $S_1$ | | $S_2$ | | $S_3$ | | $S_4$ | |
|---|---|---|---|---|---|---|---|---|
| | $\underline{A_{S_1,c}}$ | $\overline{A_{S_1 c}}$ | $\underline{A_{S_2 c}}$ | $\overline{A_{S_2 c}}$ | $\underline{A_{S_3,c}}$ | $\overline{A_{S_3,c}}$ | $\underline{A_{S_4,c}}$ | $\overline{A_{S_4,c}}$ |
| $C_{11}$ | 0.85 | 0.99 | 0.82 | 0.98 | 0.81 | 0.99 | 0.86 | 0.97 |
| $C_{12}$ | 0.90 | 0.99 | 0.85 | 0.99 | 0.89 | 0.97 | 0.91 | 0.99 |
| $C_{13}$ | 0.85 | 0.94 | 0.91 | 0.99 | 0.86 | 0.92 | 0.88 | 0.97 |
| $C_{21}$ | 0.84 | 0.94 | 0.87 | 0.96 | 0.88 | 0.99 | 0.91 | 0.99 |
| $C_{22}$ | 0.84 | 0.94 | 0.87 | 0.96 | 0.88 | 0.99 | 0.91 | 0.99 |
| $C_{23}$ | 0.91 | 0.98 | 0.90 | 0.97 | 0.92 | 0.97 | 0.87 | 0.99 |
| $C_{24}$ | 0.91 | 0.98 | 0.90 | 0.97 | 0.92 | 0.98 | 0.87 | 0.99 |
| $C_{31}$ | 0.81 | 0.95 | 0.86 | 0.97 | 0.92 | 0.95 | 0.89 | 0.93 |
| $C_{32}$ | 0.88 | 0.95 | 0.93 | 0.98 | 0.88 | 0.96 | 0.90 | 0.97 |

# ILLUSTRATIVE EXAMPLE

- Finally, we integrate the following into a **ranking of suppliers**
  - **Interval-valued** supplier **availability** capabilities
  - **Weights** associated with **component importance**
  - **Laplace rule** for comparing interval values

| Supplier | Laplace criterion $\left(\underline{D_b^\star} + \overline{D_b^\star}\right)$ | Rank |
|---|---|---|
| $S_1$ | 0.631 | 4 |
| $S_2$ | 1.596 | 3 |
| $S_3$ | 1.857 | 1 |
| $S_4$ | 1.607 | 2 |

# ILLUSTRATIVE EXAMPLE

- For this particular illustration, the ranking of suppliers differs slightly when considering a **point estimate** for availability
  - Relative to **interval values** and the **Laplace rule**

| Supplier | Interval uncertainty $\left(\underline{D_b^\star} + \overline{D_b^\star}\right)$ | Interval uncertainty Rank | Point estimate $D_b^\star$ | Point estimate Rank |
|---|---|---|---|---|
| $S_1$ | 0.631 | 4 | 0.5741 | 3 |
| $S_2$ | 1.596 | 3 | 0.2129 | 4 |
| $S_3$ | 1.857 | 1 | 0.6391 | 1 |
| $S_4$ | 1.607 | 2 | 0.5952 | 2 |

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# CONCLUDING REMARKS

- This work provided two important perspectives
- **First**, determining **component importance** based on **system availability**
- **Second**, using availability-based importance to **rank sole suppliers** of components
- Ultimately addressing "**how do we build in system availability through appropriate supplier selection?**"

# CONCLUDING REMARKS

- We'd like to extend our formulation for more **complex systems**
  - i.e., those systems that don't fall into the **traditional four system designs** for which analytical solutions exist
  - Could then describe selection of suppliers of, say, **infrastructure network services**

- This work resulted in two published/accepted papers

# END OF PRESENTATION

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